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Relationship between Length of Roundtail Chub and Infection Intensity of Asian Fish Tapeworm *Bothriocephalus acheilognathi*

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Abstract.—Nonnative parasites have been blamed for the decline of native fish species in the American Southwest. The Asian fish tapeworm *Bothriocephalus acheilognathi* has parasitized many native fish species, but little is known of its effects on native cyprinid fish hosts. I found a strong negative correlation (Spearman's rank correlation, $r_s = -0.846$; $P < 0.001$) between total length of roundtail chub *Gila robusta* and number of Asian fish tapeworms. A significant, but weaker negative correlation existed between weight of fish and number of tapeworms ($r_s = -0.687$; $P < 0.001$). In addition, infected fish were significantly shorter ($P = 0.0241$) than uninfected fish. Infection by Asian fish tapeworm may slow growth, increase susceptibility to infestation, and increase predation on roundtail chub and possibly other native cyprinids.

The roundtail chub *Gila robusta* is one of a diverse group of native cyprinids that was once widely distributed throughout the Colorado River basin. Historically, roundtail chub in Arizona have been reported from the Colorado, Bill Williams, Gila, Little Colorado, Salt, and Verde river drainages (Girmendonk and Young 1997). In 1986 roundtail chub were absent from nearly half (42%) of the Arizona streams and rivers where they were found historically. Roundtail chub have been extirpated from an additional 19% of historic locations in the last decade, causing this species to become one of ''special concern'' in Arizona.

Altered flow regimes (e.g., dams, water diversions, and land use practices) and predation or competition by introduced nonnative fishes have been blamed for declines in roundtail chub and other native fish populations in the American Southwest (Miller 1961; Minckley and Deacon 1968; Minckley and Douglas 1991). Nonnative fish translocations inadvertently introduced nonnative parasites into this area (Hoffman and Shubert 1984; Heckmann et al. 1986). The Asian fish tapeworm *Bothriocephalus acheilognathi* has parasitized many native fish species in this region (Heckmann et al. 1986, 1987; Brouder and Hoffnagle 1997; Clarkson et al. 1997). The tapeworm's life cycle includes two hosts: a cyclopoid copepod (Marcogliese and Esch 1989) and, usually, a cyprinid host (Granath and Esch 1983).

Since its detection in the Colorado River basin in 1979, the Asian fish tapeworm has rapidly expanded its distribution to several different drainages within the basin (Heckmann et al. 1993). Clarkson et al. (1997) emphasized growing concern that the parasite may expand its distribution to lower-elevation drainages where nearly half the native fishes are cyprinids and most are endangered, threatened, or of special concern. Although not documented in the Verde River basin (Robinson et al. 1998), *B. acheilognathi* has infected fish cultured at Bubbling Ponds Hatchery within the basin.

Understanding the prevalence and geographic distribution of parasites is a high priority for developing management strategies (Moffitt et al. 1998). However, before management strategies can be implemented, information regarding the effects of parasites on their fish hosts is needed. Knowledge of pathological or chronic effects of *B. acheilognathi* on native cyprinid hosts is limited but may include blockage of the gastrointestinal tract, intestinal perforation, destruction of the intestinal mucosa, reduced growth, or suppressed swimming ability, ultimately causing mortality (Hoffman 1980; Heckmann et al. 1986; Schäperclaus 1986). The objective of this study was to determine prevalence of *B. acheilognathi* in cultured roundtail chub and the relationship between numbers of this parasite and total length of this native fish.

Methods

Adult roundtail chub were collected from the upper 120 km of the Verde River, Arizona, and transported to Arizona Game and Fish Department's Bubbling Ponds Hatchery in Cornville, Arizona. Broodfish were artificially spawned, progeny were raised in the laboratory, and fry were reared in a pond. All fish were of the same spawn and were exposed to the same physical, chemical,

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and biological variables within the pond. Fish were randomly sampled from the hatchery pond in July and August 1998 using a fyke net, measured for total length (TL, mm) and weight (g), and preserved in 70% isopropyl alcohol. Gastrointestinal tracts were removed in the laboratory and numbers of adult *B. acheilognathi* were counted. Initial identification of this distinctive tapeworm was made in the laboratory and later confirmed using Mitchell's (1994) key. Roundtail chub were accidentally infected via infected livebearers *Gambusia* sp. from springs that supply water to the hatchery ponds. Individual Spearman rank correlation coefficients (r_s) were calculated to determine associations between TL or weight of roundtail chub and the number of tapeworms found in each fish. Mann–Whitney *U*-tests were used to determine differences in TL or weight of infected versus uninfected fish with significance at $\alpha = 0.05$ (Sokal and Rohlf 1981).

Results and Discussion

Fifty-two roundtail chub ranging in TL from 110 to 201 mm (mean, 155.6 mm) and weight from 8 to 67 g (mean, 34.5 mm) were collected. Forty-four of 52 (84.6%) fish were infected with the tapeworm, and the majority of worms were found in a ''clump'' in the anterior portion of the gastrointestinal tract. Intensity of infection was 24.1 tapeworms per fish examined or 28.3 tapeworms per infected fish and ranged from 0 to 146 tapeworms per fish. I found a strong negative correlation between total length of fish and number of tapeworms ($r_s = -0.846$; $P < 0.001$). A significant, but weaker negative correlation existed between weight of fish and number of tapeworms ($r_s = -0.687$; $P < 0.001$). In addition, infected fish were significantly shorter ($P = 0.0241$) than uninfected fish, but there was no significant difference in weight between infected and uninfected fish ($P = 0.6342$). As compared with total length, the weaker correlation between weight and number of tapeworms may be explained by the variability associated with numbers of tapeworms per fish or size of tapeworm. Abdomens were distended, as if fish had recently fed; and externally, fish looked ''healthy.'' However, during necropsy it became apparent that the enlarged abdomen was due to the presence of tapeworms, elevating weights of individual fish.

Growth of fishes is influenced by water temperature, dissolved oxygen, amount and size of available food, number of fish using the resources, age of fish (Everhart and Youngs 1981; Moyle and Cech 1988), and genetic predisposition (Mitton and Grant 1984). All fish in this study were of essentially the same age and were exposed to the same physicochemical conditions. Therefore, effects of these variables were probably minimal. A strong negative association between total length and infection intensity, along with a significant difference in total length of infected versus uninfected fish, indicates that tapeworm infection may have slowed growth of fish. It is not clear whether these results indicate a cause and effect relationship (i.e., tapeworms caused slower growth). However, results are probably not due solely to natural variability in growth, genetic predisposition of hosts, or variability in parasites but may be a combination of at least two of the three.

Infection intensity may be higher in small fish as a result of differential diet among size of fish. In systems where *B. acheilognathi* is present, small fish are more likely to feed upon cyclopoid copepods than large fish (Vanicek and Kramer 1969; Minckley 1973; Sublette et al. 1990) and may be more susceptible than larger fish to infection by the tapeworm. Once infected, growth may slow and increase the likelihood of continued consumption of copepods and, therefore, increase infection.

Mechanisms contributing to (1) the negative associations between total length and weight of roundtail chub and number of tapeworms and (2) the significant difference in total length of infected versus uninfected fish are uncertain (i.e., tapeworms slow fish growth or slower growth results in more tapeworms). Nonetheless, results raise concerns regarding conservation of roundtail chub and other native fish species. If fish grow slower once infected, continued susceptibility to infestation is likely, as is increased susceptibility to predation since fish remain at a smaller size for a longer period of time. Predation on native fishes due to planned or inadvertent introductions of nonnative fish species is a major contributing factor to the decline in native fishes (Minckley 1991; Marsh and Douglas 1997), and smaller fish are more prone to predation (Marsh and Brooks 1989). Further studies to determine the effects of parasite infection on growth of native fishes, as well as potential increased susceptibility to predation are needed, as these may be additional factors contributing to the decline of native fish species.

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